Antimicrobials Used in Cooling Water Systems

EPA/OCSPP/OPP/Antimicrobials Division Training

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Antimicrobials Used in Cooling Water Systems – Overview of Presentation

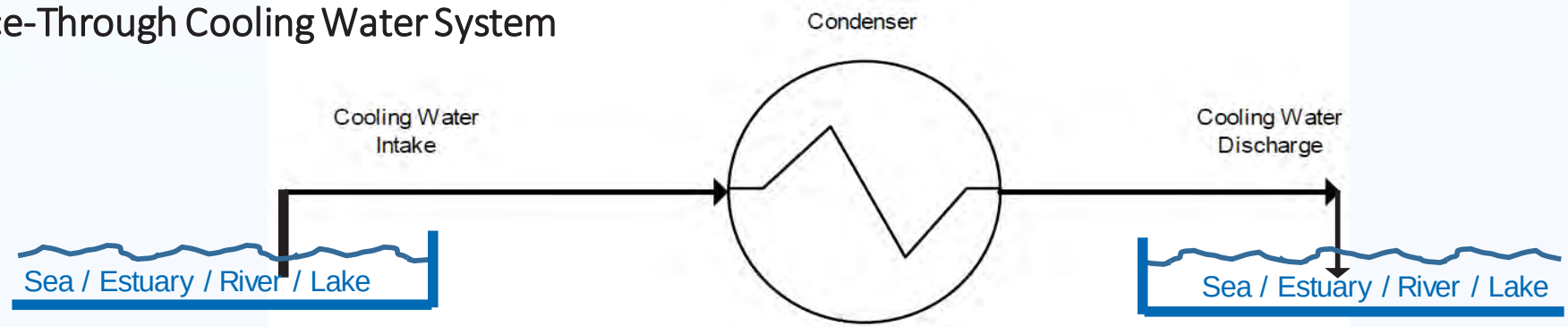
- Function of cooling water systems
- Types of cooling systems – recirculating and once-through
- Biofouling potential in once-through versus recirculating cooling water systems
- Basic approaches for modeling ecological exposures
- Ecological exposure modeling methodology for cooling water systems
- Evaluating potential effects to aquatic organisms
- Evaluating potential dietary exposure and effects to humans from ingestion of drinking water and fish

Antimicrobials Used in Cooling Systems – Cooling Water System Function and Types

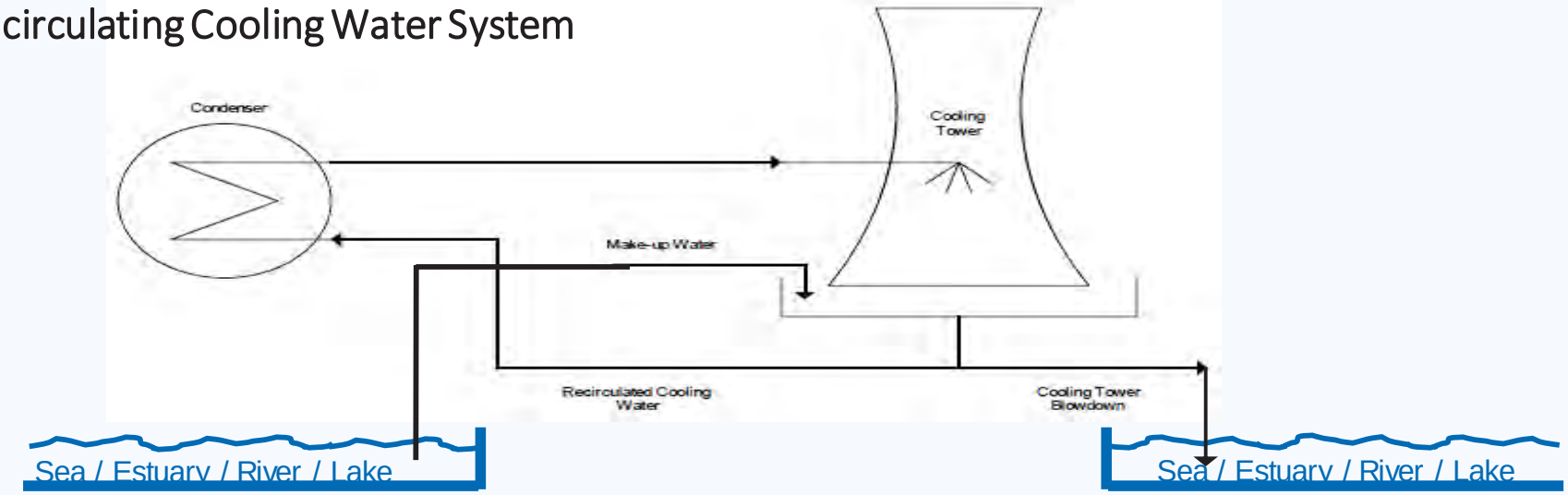
- The function of a cooling system is to remove heat from processes or equipment
- Heat removed from one cooling medium is transferred to another medium or process fluid, usually water
- Heated water can be handled in one of two ways –
  - The water can be discharged at the increased temperature into a receiving body (once-through cooling (OCT) system) or
  - it can be cooled and reused (recirculating cooling system)

General Types of Cooling Water Systems

Once-Through Cooling Water System



Recirculating Cooling Water System



Source: Modified from USEPA 2006. Interim Detailed Study Report for the Steam Electric Power Generating Point Source Category. Engineering and Analysis Division, Office of Water, Washington, DC. 821-R-06-015 128 pp.

Antimicrobials Used in Cooling Systems – General Information

- Two categories of cooling water systems:
  - electric generating facilities (2,138) and
  - industrial non-utilities (908)
- In the US 90% of electricity comes from thermoelectric power plants (coal, nuclear, natural gas, and oil); the remaining 10% is produced by hydroelectric and other renewable energy facilities (UCS, 2012)
- Of thermoelectric generators in the US, 43% use once-through cooling and 56% use recirculating (UCS, 2012)
- According to USEPA (2009) types and numbers of electric generating facilities in the US in 2002 include:
  - Hydroelectric power (416)
  - Fossil fuel electric power (1233)
  - Nuclear electric power (78)
  - Other electric power (411)
- Electric generating facilities can have more than one generating unit

Antimicrobials Used in Cooling Water Systems – General Information

- Steam Electric Facilities Using Once-Through Cooling (OTC) Water Systems:
  - Use large amounts of water
  - EPA calculated a discharge rate of 230 MGD per cooling water system (USEPA, 2006)
  - Based on industry survey data, the average flow rate was approximately 305 million gallons per day (MGD) per cooling water system (USEPA, 2006)
- Very few new power plants use once-through cooling because of the disruptions such systems cause to local ecosystems from the significant water withdrawals involved and because of increased difficulty in siting power plants near available water sources

Antimicrobials Used in Cooling Water Systems – General Information

- Steam Electric Facilities Using Recirculating cooling water systems:
  - Use smaller amounts of water than facilities using a once-through system
  - Based on industry survey data, the average blowdown flow rate was 0.94 MGD (USEPA 1982 as cited in USEPA 2006); EPA calculated a flow rate of 6.04 MGD (USEPA 2006b as cited in USEPA 2006)
  - Require only about 5% of the water that OTC systems require (USEPA 1982 as cited in USEPA 2006)
  - Discharge less than 1% of the flow typical of once-through systems (USEPA, 1982)

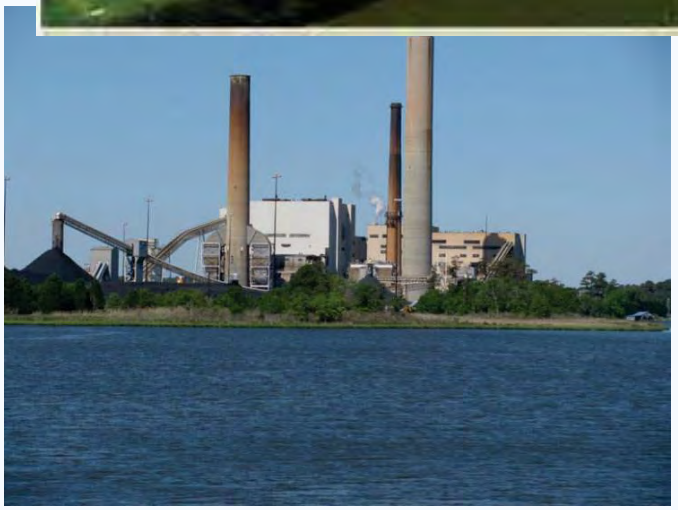
Antimicrobials Used in Cooling Systems – Recirculating Cooling Systems

- Recirculating systems can be open or closed
- In an open recirculating system:
  - Cooling is achieved through evaporation which results in a loss of pure water from the system and a concentration of the remaining dissolved solids
  - Water must be removed, or blown down, to control concentration of dissolved solids and fresh water must be added to replenish the system
- In a closed recirculating system:
  - Water losses are usually small; little, if any, evaporation occurs
  - Water circulates in a closed cycle and is subjected to alternate cooling and heating without air contact
  - There is less susceptibility to biological fouling from slime and algae deposits than open systems

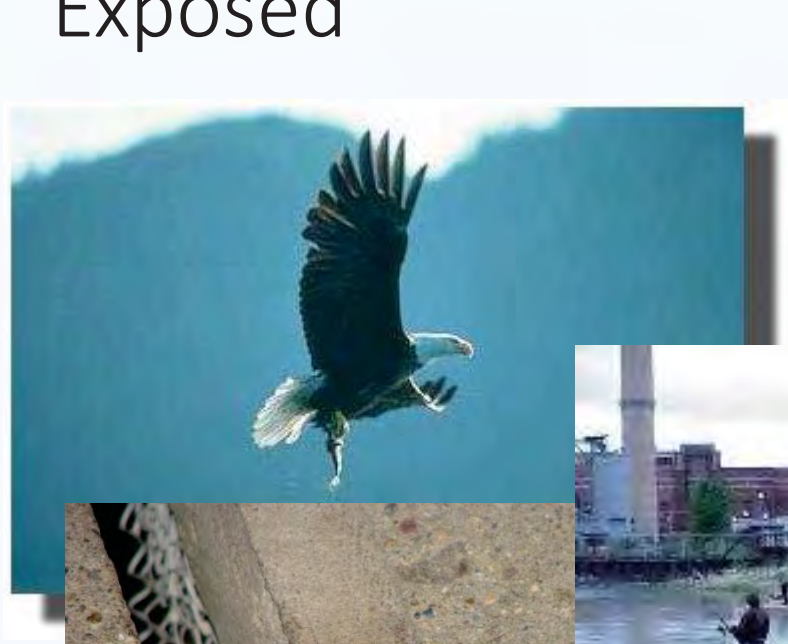
Antimicrobials Used in Cooling Systems – Biofouling

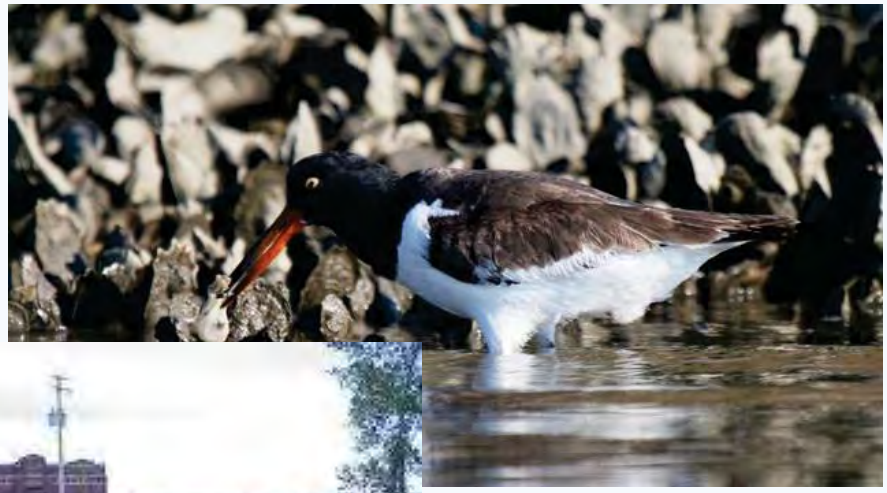
- Microbiological fouling in cooling systems is the result of abundant growth of algae, fungi, and bacteria on surfaces
- Microbial growth on wetted surfaces can lead to formation of biofilms which can cause fouling and can adversely affect equipment performance, promote metal corrosion, and accelerate wood deterioration
- Recirculating cooling water systems:
  - open or closed recirculating water systems may support microbial growth, but fouling problems usually develop more quickly and are more extensive in open recirculating systems
  - Microbial growth is more rapid since microbes are scrubbed from the air and concentrate nutrients present in makeup water through evaporation
- Once-through cooling water systems:
  - Since once-though systems contain relatively low levels of nutrients essential for microbial growth, growth is relatively slow

Variety of Aquatic Ecosystems Exposed to Discharged Cooling Water from Facilities

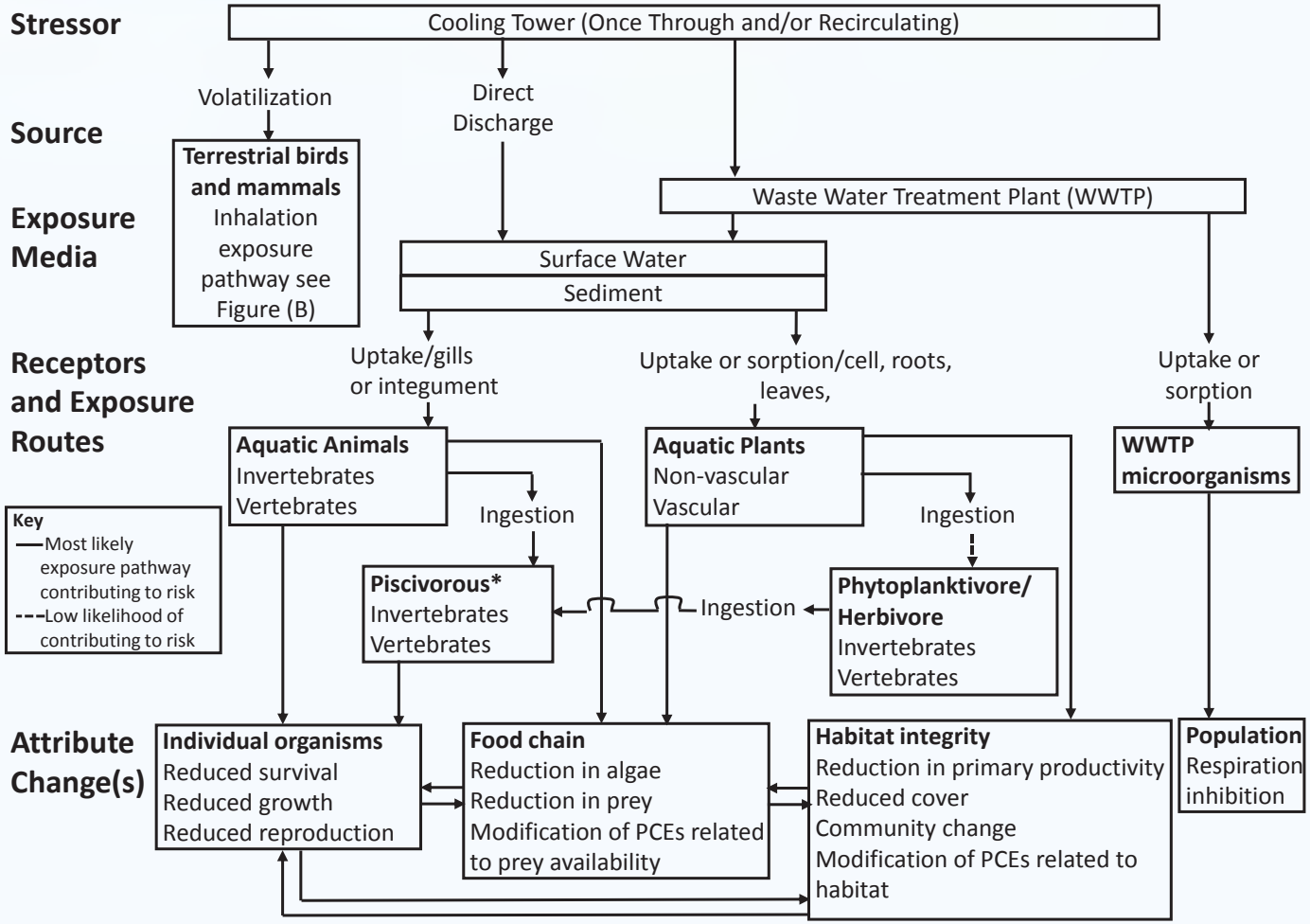


Also Potential for Terrestrial Animals to be Exposed





Ecological Conceptual Exposure Model Diagram



*As used here this term refers to animals (terrestrial or aquatic) that eat not just fish but any aquatic animal (*e.g.*, amphibians, mollusks, crustaceans, *etc.*)

Ecological Exposure Modeling Methodology – Freshwater Organisms in the Water Column

- Exposure modeling estimates concentrations of an antimicrobial in the dissolved phase of the water column
- For flowing freshwater bodies (e.g., rivers and streams) the ratio of the distribution of stream flows to cooling water system discharge flows are used to predict exposure
- AD generally uses the General Population and Ecological Exposure from Industrial Releases Module of Exposure and Fate Assessment Screening Tool (E-FAST) with the probabilistic option
- The probabilistic approach estimates the number of days per year of release to the aquatic environment that a concentration of concern for aquatic organisms is exceeded

Ecological Exposure Modeling Methodology – Freshwater Organisms in the Sediment

- To assess exposure in sediments AD uses a risk quotient (RQ) approach
- In the RQ approach, RQ = estimate of the concentration of antimicrobial in sediment divided by ecotoxicity endpoint value (LC_{50} and NOAEC) for freshwater benthic organisms
- If RQ>1, the level of concern (LOC) for risk to freshwater benthic organisms is exceeded indicating potential concern
- Sediment concentrations are determined by multiplying average leaching adsorption/desorption values by concentrations of antimicrobial in surface water predicted by E-FAST

Ecological Exposure Modeling Methodology – Estuarine/Marine Organisms in the Water Column

- To assess exposure of estuarine/marine organisms exposed to antimicrobials primarily via the water column AD uses a risk quotient approach
- Since estuarine/marine water bodies have no stream flows, it is inappropriate to use concentrations based on E-FAST results
- A screening level approach based on concentrations of antimicrobial at the point of discharge of cooling water prior to entry into the water body is used (aka end-of-pipe concentrations)
- RQs are estimated by dividing end-of-pipe concentrations by toxicity endpoints for estuarine/marine organisms exposed via the water column
- AD then determines dilution factors that would be needed to minimize potential risks

Ecological Exposure Modeling Methodology – Benthic-Dwelling Estuarine/Marine Organisms

- A risk quotient method is used
- An upper bound estimate of exposure based on a residual concentration of antimicrobial at the discharge point (end-of-pipe concentration) is used to derive concentrations of antimicrobial in sediments
- Worst case sediment concentrations are determined by multiplying average leaching adsorption/desorption values by end-of-pipe concentrations of antimicrobial
- The risk quotient for estuarine benthic organisms is determined by comparing the worst case sediment exposure estimate to the available toxicity data for the most sensitive estuarine/marine organism

Ecological Exposure Modeling Methodology – Recirculating Cooling Water Systems

- Exposure to aquatic organisms is assumed to result predominantly from release of blowdown water
- Key input parameters required to estimate recirculating cooling system exposures include:
  - Environmental release of antimicrobial to surface water (kg/site/day)
  - Concentrations of concern (COC) for aquatic organisms (ug/L)
  - Standard Industrial Classification (SIC) code to represent the ratio of stream flows to plant flows for cooling water system facilities (usually SIC 4911 – Steam Electric Power Plants)
  - Percent removal of antimicrobial during wastewater treatment
  - Annual number of days of release to surface water (days per year)
  - Selection of high-end or average case scenario

Ecological Exposure Modeling Methodology – Recirculating Cooling Water Systems

- The approach used to estimate potential exposures of freshwater organisms in the water column to antimicrobials released to surface water from recirculating cooling system blowdown water can be described in four steps
- STEP 1: Estimate environmental release to surface water from recirculating cooling system blowdown water (kg/site/day)
- STEP2: Determine percent removal of antimicrobial during wastewater treatment
- STEP 3: Derive concentrations of concern (COCs) for aquatic organisms from LC_{50} and NOAEC values
- STEP 4: Estimate aquatic exposures from releases of recirculating cooling system blowdown water to surface water using the general population exposures from industrial releases module of E-FAST

Modeling Recirculating Cooling Water Systems – STEP 1: Release via Blowdown

- Daily release estimate of kg/site/day antimicrobial is based on a generic scenario developed by OPPT/CEB
- Estimate is derived from information on concentration of antimicrobial in recirculating cooling water system and recirculation rate of cooling water
- Concentration in cooling water is based on information from the product label
- Recirculation rates of cooling water assumed are 2000 gallons per minute for a moderate-size cooling system and 100,000 gallons per minute for a large-size system
- Blowdown is assumed to be about 0.6% of water used

Modeling Recirculating Cooling Water Systems – STEP 2: WWTP Percent Removal

- Key wastewater treatment plant fate tests include:
  - biodegradability in WWT and
  - sorption to activated sludge
- These tests were discussed in the presentation on environmental fate and transport
- An estimation program such as the STP module of EPI-WEB can be used to determine percent removal during wastewater treatment, but will tend to underestimate biodegradation potential
- To determine percent removal of antimicrobial during wastewater treatment , information from wastewater treatment plant (WWTP) fate tests is usually preferred to estimation methods
- Data from OW treatability study can be used for metals (e.g., Copper, Silver)

Modeling Recirculating Cooling Water Systems – STEP 3: Estimate COCs

- EPA's modeling results are expressed as number of days per year of exceedance of COCs for aquatic organisms
- The Agency uses the most "sensitive" ecotoxicology endpoints for surrogate species to assess risk to each aquatic receptor group (e.g., freshwater fish, freshwater invertebrates, aquatic plants)
- COCs for acute effects were determined by dividing LC_{50} values from acute toxicity tests on aquatic vertebrates and invertebrates by 2
- COCs for chronic effects for non-listed species were based on No Observed Adverse Effects Concentration (NOAEC) values from tests on aquatic vertebrates and invertebrates
- COCs for listed endangered and threatened aquatic organisms were determined by dividing LC_{50} values from acute toxicity tests on aquatic vertebrates and invertebrates by 20
- Acute COCs for aquatic vascular plants and algae are based on EC_{50} values; COCs for endangered algae and aquatic vascular plants are based on NOAEC values

Modeling Recirculating Cooling Water Systems – STEP 4: Estimate Eco Exposure

- Using results from Steps 1 through 3 as inputs, the General Population and Ecological Exposure from Industrial Releases module of E-FAST is used to estimate the number of days of exceedance of COCs for aquatic organisms
- The model provides estimates for both high-end and average case exposure scenarios
- The high-end scenario is based on the 10th percentile of the ratio of the 7Q10 (i.e., lowest 7 consecutive-day stream flow over a 10-year period) stream flows to plant flows
- The average case scenario is based on the 50th percentile of the ratio of the 7Q10 stream flows to plant flows
- The SIC code selected is used to provide data on the ratio of stream flows to plant flows (usually SIC 4911 – Steam Electric Power Plants)

Modeling Once-Through Cooling Water Systems

- The same four steps that are used to model exposures for recirculating cooling water systems are used for once-through cooling water systems
- The concept used to estimate kg/site/day antimicrobial released to surface water in Step 1 for once-through cooling water systems is similar to that for recirculating cooling water systems
- One key difference: for a recirculating system, release of antimicrobial to surface water is limited to blowdown water; for a once-through system, release of active ingredient to surface water is based on the total throughput
- The resulting eco exposure estimate in STEP 4 reflects the exposure based on total throughput

Cooling Water System Ecological Effects Data Requirements-Changes

- Represents a high environmental exposure use pattern
  - ✓One of the more comprehensive data requirement use pattern
- Once through system
  - Four new data requirements
    - Activated sludge respiration inhibition (ASRI) test
    - Sediment testing, Freshwater and Estuarine/Marine Benthic invertebrates
    - Tier II plant testing-no Tier I
  - Recirculating system use patterns
  - ✓Data requirements do not differ from once through systems
    - Change from historic treatment of recirculating systems as “indoors” with little or no exposure
    - Historically recirculating use pattern had a more limited data requirement as compared to once-through
    - Modeling now addresses difference in loading between once-through and recirculating systems in terms of exposure estimates

Type of Organisms for Which Data are Required

- Birds
- WWTP Organisms
- Plants
- Aquatic Invertebrates
- Benthic Invertebrates
- Fish

Ecological Effects Data Requirements: Example Assumptions and Key

- The example is based on the data requirements in the non-target animal and plant protection tables under "Industrial Processes and Water Systems" Use Pattern
- The active ingredient is assumed to be:
  - Persistent (Stable)
  - Bioaccumulative—i.e. $K_{ow} \geq 1000$
  - Partitions to sediment—i.e. $K_{ow} \geq 1000$
- Table key
  - R: required data
  - CR: conditionally required data

Required to conduct ecological risk assessment (includes CR data because the example fate assumptions meet the test note conditions).

Additional information such as toxicity data from lower tier data requirements, or information regarding components of the formulation or exposure are needed to inform the conditional requirements.

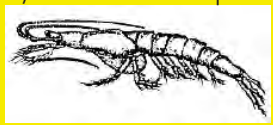
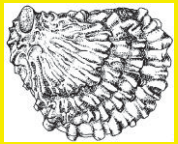
Cooling Water Systems—Effects Data Requirements: Birds and WWTP Micro-organisms

Receptor Group and Test Type	To Support MP and EP Test Substance TGAI
Birds	
Acute oral	**R** two tests: one water fowl and one upland game bird species
Dietary	**CR** one water fowl or one upland game bird species (**Required if** any of the acute oral values are ≤100 mg ai/L [in this case species used in test should be the more sensitive of the acute oral test results])
Reproduction	**CR** one water fowl and one upland game bird species Required in this example because established ai is persistent (i.e., stable), bioaccumulative (Kow ≥1000) and use results in repeated exposure.
WWTP micro-organisms	
SRI	**R**

Cooling Water Systems—Ecological Effects Data Requirements: Plants

Receptor Group and Test Type	To Support Registration of:	
	MP and EP	EP
	Test Substance	
	TGAI	EP
Plants		
Seedling emergence	**CR** rice (**Required if** any algal or aquatic vascular RQ > 1)	
Vegetative vigor	**CR** rice (**Not Required if** hydrolysis half-life <5 days, or ai and priciple degradates biodegrade in 28 days, or no plants will be expose) **Required** for this example because stable and plants are potentially exposed	
Aquatic vascular	**R** duckweed	**CR** duckweed (**Required if** ingredient in EP other than ai enhances toxicity of ai)
Algal	**R** green algae, freshwater diatom, saltwater diatom, cyanobacteria	**CR** green algae, freshwater diatom, saltwater diatom, cyanobacteria (**Required if** ingredient in EP other than ai enhances toxicity of ai)
Terrestrial field		**CR** Case-by-case
Aquatic field		**CR** Case-by-case

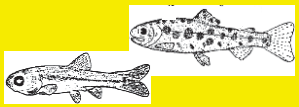
Ecological Effects Data Requirements: Water Column Invertebrates

Receptor Group and Test Type	To Support Registration of:	
	MP and EP	EP
	Test Substance	
	TGAI	EP
Aquatic Invertebrates		
FW Acute 	**R** one species	**CR** one species-same as that tested with the TGAI (**Required if** an ingredient(s) in EP other than ai enhances toxicity of ai; or if EEC ≥0.5 x TGAI EC_{50}; or if $7Q10_{0.10}$ exceeds acute COCs ≥4 days)
E/M Acute Shrimp 	**CR** one penaeid species (**Required if** the residues from the ai and/or transformation products are likely to enter the estuarine/marine environment) **Required** for cooling water systems because unless label specifically prohibits discharge to estuarine/ marine systems, this use pattern can result in discharge to estuarine/marine systems.	**CR** one species-same as that tested with the TGAI (**Required if** an ingredient(s) in EP other than ai enhances toxicity of ai; or if EEC ≥0.5 x TGAI LC_{50}; or if $7Q10_{0.10}$ exceeds acute COCs ≥4 days)
E/M Acute Mollusk 	**CR** one species (**Required if** the residues from the ai and/or transformation products are likely to enter the estuarine/marine environment) **Required** for cooling water systems because unless label specifically prohibits discharge to estuarine/ marine systems, this use pattern can result in discharge to estuarine/marine systems.	**CR** one species-same as that tested with the TGAI (**Required if** an ingredient(s) in EP other than ai enhances toxicity of ai; or if EEC ≥0.5 x TGAI IC_{50}; or if $7Q10_{0.10}$ exceeds acute COCs ≥4 days)
Life Cycle	**R** one species (The more acutely sensitive of the freshwater or estuarine/marine invertebrate shrimp species-if label prohibits discharge to E/M can just test FW) If the life cycle test is conducted with a species different from those tested in the acute studies, an acute test with the life cycle test species would also be required to allow calculation of an ACR for use in estimating chronic values for at least the most acutely sensitive species	

Ecological Effects Data Requirements: Benthic/Sediment Invertebrates

Receptor Group and Test Type	To Support Registration of:
	MP and EP
	Test Substance
	TGAI
Whole sediment, subchronic freshwater invertebrates	**CR** one amphipod and one chironomid species (**Required if** test note conditions are met)
Whole sediment, chronic freshwater invertebrates 	**CR** one amphipod and one chironomid species (**Required if** test note conditions of sediment sorption and persistence are met) **Required** for stable ai with Kow ≥1000 unless label prohibits discharge to freshwater environments.
Whole sediment, subchronic marine invertebrates	**CR** one amphipod species (**Required if** test note conditions are met)
Whole sediment, chronic marine invertebrates 	**CR** one amphipod and one chironomid species (**Required if** test note conditions of sediment sorption and persistence are met and label does not prohibit discharge to estuarine/marine environment) **Required** for stable ai with Kow ≥1000 unless label prohibits discharge to freshwater environments.

Ecological Effects Data Requirements: Fish and Aquatic Animal Testing

Receptor Group and Test Type	To Support Registration of:	
	MP and EP	EP
	Test Substance	
	TGAI	EP
Fish		
Freshwater (FW) Acute	**R** one cold water and one warm water species 	**CR** one species-most sensitive species of the TGAI tests (**Required if** an ingredient(s) in EP other than ai enhances toxicity of ai; or if EEC ≥0.5 x TGAI LC_{50}; or if $7Q10_{0.10}$ exceeds acute COCs ≥4 days)
Estuarine/Marine (E/M) Acute 	**CR** one species (**Required if** the residues from the ai and/or transformation products are likely to enter the estuarine/marine environment) **Required** for cooling water systems because unless label specifically prohibits discharge to estuarine/ marine systems, this use pattern can result in discharge to estuarine/marine systems.	**CR** one species--same species as TGAI (**Required if** an ingredient(s) in EP other than ai enhances toxicity of ai; or if EEC ≥0.5 x TGAI LC_{50}; or if $7Q10_{0.10}$ exceeds acute COCs ≥4 days)
Early Life Stage (ELS)	**R** one species (The more acutely sensitive of the FW or estuarine/marine species-if label prohibits discharge to E/M can just test FW) If the ELS test is conducted with a species different from the acutes, an acute test using the ELS species is also required to allow calculation of an ACR for use in estimating chronic values for at the most acutely sensitive species.	
FW Fish Full Life Cycle	**CR** one species* (**Required** if it is a known reproductive toxicant, or if EEC >0.1 x ELS or invertebrate NOAEC; or if $7Q10_{0.10}$ exceeds chronic COC ≥20 days)	
SW Fish Full Life Cycle	**CR** one species* (**Required** if it is a known reproductive toxicant, or if EEC >0.1 x ELS or invertebrate NOAEC; or if $7Q10_{0.10}$ exceeds chronic COC ≥20 days)	
Simulated or actual field testing for aquatic animals		CR (Case-by-case: to address significant risks and uncertainties)

*May need an additional acute test for species used in fish full life cycle: full life cycle typically conducted on species that completes life cycle in months versus years, need to be able to calculate an ACR to apply to more acutely sensitive species

Ecological Effects Data Requirements: Bioconcentration, Food Chain Transfer

Receptor Group and Test Type	To Support Registration of:
	MP and EP
	Test Substance
	TGAI, PAI, degradate
Fish bioconcentration	**CR** one species (**Not required if** ultimate degradation is rapid, Kow <1000, and exposure unlikely) Required for example ai because it is stable, Kow≥1000, and cooling water is discharged to surface water)
Oyster bioconcentration	**CR** one species (**Not required if** ultimate degradation is rapid, Kow <1000, and exposure unlikely) Required for example ai because it is stable, Kow≥1000, and cooling water is discharged to surface water)
Food chain transfer study	**CR** (Case-by-case: to address uncertainties in food chain transfer and refine risks from food chain transfer)

Ecological Effects Data Requirements—Factors To Consider

- May have physical/chemical properties, fate, or exposure conditions requiring less data
  - ❑Examples
    - ✓Parent and major degradates do not partition to sediment (i.e., K_{ow} <1000, K_{oc} <1000, K_d<50 g/L) – sediment data not required
    - ✓Label language prohibits cooling water or cooling water effluent discharge to estuarine/marine surface waters
    - ✓Label language prohibits cooling water or cooling water effluent discharge to freshwater surface waters
- May have physical/chemical properties, fate, or exposure conditions requiring additional and/or alternative data
  - ❑Examples:
    - ✓Parent not stable, but forms a major degradate which is stable – some tests will need parent, some only the major degradate, some will need both
    - ✓pKa in an environmentally relevant pH range—need tests to be conducted under pH conditions which result in the most bioavailable form being present or may need aquatic test data that brackets the pKa where half is unionized and half is ionized

Dietary Exposure Assessment Overview

- Risk is a function of hazard and exposure
- Exposure from both drinking water as well as fish are considered
- Modeled using the Dietary Exposure Evaluation Model-Food Commodity Intake Database (DEEM-FCID)
  - Acute, chronic, and cancer assessments can be conducted
  - Nine subpopulations of interest: General US Population, All Infants (<1 year), Children 1-2, Children 3-5, Children 6-12, Youth 13-19, Adults 20-49, Adults 50+, and Females 13-49
  - Consumption data from the 2003-2008 USDA What We Eat In America (WWEIA) survey that was conducted as part of the National Health and Nutrition Examination Survey (NHANES)
    - Nationally representative/statistically-based
    - Collected on a two-year continuous basis (~10,000 individuals, ~7,000 foods)
  - Outputs are based on the percentage of the population adjusted dose (% PAD)

Dietary Exposure Assessment Drinking Water and Fish

- Drinking Water
  - Estimated drinking water concentrations (EDWCs) are used as inputs
    - E-FAST
    - End-of-pipe
  - EDWCs are incorporated in DEEM-FCID into the food categories “water, direct, all sources” and “water, indirect, all sources”
  - For a recent case in order to be conservative, the end-of-pipe EDWC was used for the dietary exposure assessment and no risks of concern were identified for any sub-populations
- Fish
  - Residues in fish can also be a concern for subsistence and recreational fisherman
  - The OPP SciPoc (Science Policy Council) is currently evaluating an OPP-wide method for addressing possible exposures from fish consumption

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